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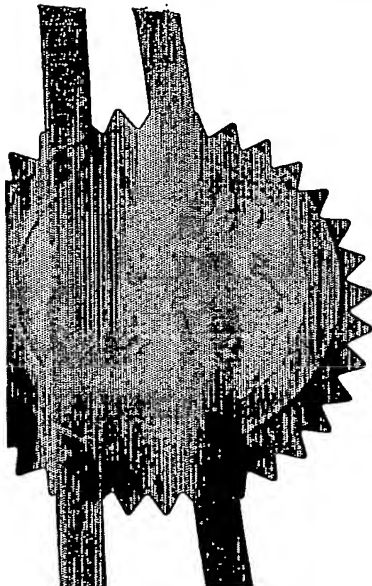
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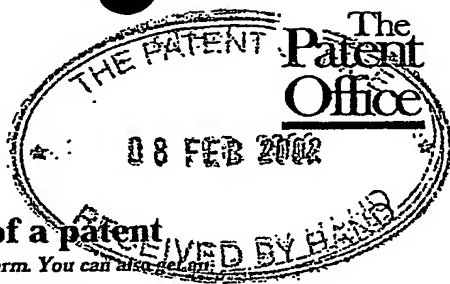
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Norsk Hydro ASA
N-0240 Oslo
Norway

Patents ADP number *(if you know it)* 0714269002

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Norway

4. Title of the invention

METHOD OF DETERMINING A HEAT TREATMENT

5. Name of your agent *(if you have one)*

Gill Jennings & Every

"Address for service" in the United Kingdom to which all correspondence should be sent *(Including the postcode)*

Broadgate House
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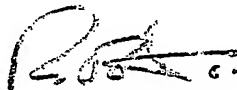   and search *(Patents Form 9/77)*   1

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METHOD OF DETERMINING A HEAT TREATMENT

The present invention relates to a method of
determining a heat treatment to apply to a structural
member, in particular to modify the deformation behaviour
of the structural member when subjected to an applied
stress.

In a vehicle crash situation, energy absorbing
structures experience large variations in the local
stresses and strains. While some regions of a member need
to withstand high stresses, other areas are required to
accommodate high strains in order to avoid problems of
brittle fracture. The particular alloy, for example an
aluminium alloy, that is chosen for the structure should be
selected with both of these criteria in mind.

Increasing the gauge thickness in the product will
normally solve the stress requirements but not without
suffering a weight penalty. Quite often, high strength
alloys are not suitable in crash absorbing products due to
their limited ability to withstand high strains in exposed
regions of the part. Traditionally, the solution to this
problem is to select a more ductile alloy with less yield
strength. This again brings back the problem of
insufficient strength of the structure, which must be
compensated by increasing the gauge thickness.

When designing automotive parts, due attention must be
given to the deformation behaviour of the structure when it
is submitted to high stresses or strains, for example
during an accident. In particular, the front and rear
bumper beams represent particularly exposed regions and
large efforts are put in controlling the deformation
behaviour of these. The more energy that can be absorbed in
the outer part of the structure, the less damage is caused
to the remaining internal part of the structure of the
vehicle.

When constructing bumper beams, different methods are used in order to control the deformation behaviour. For example the use of tilted partitions and non-uniform plate thicknesses makes it possible to attain favourable deformation behaviours. Such physical geometrical features are however demanding and expensive to produce. Great effort is therefore directed at the construction of the simplest possible structure, which also exhibits the best possible deformation behaviour.

One example of a composite bumper of this kind is described in US4252355 where the bumper section is integrally moulded with lugs, the bumper section and lugs each containing elongated reinforcement fibres. The energy of a crash is absorbed at least in part by the deformation of the lugs.

To enhance the effectiveness of bumper beams, crash boxes are being introduced between the inner vehicle structure and the external structure. When the forces on a crash box exceed certain critical values it deforms and thereby absorbs energy.

As is the case for bumper beams, the deformation behaviour of a crash box during an impact is critical. If the crash box resists too high a stress, its impact absorbing capacity will occur after damage is done to the vehicle structure. If there are protrusions or holes in the side walls of the crash box, they will generate local zones of high stress concentrations. The possibility of local crack propagation in these zones is thereby increased due to the stress concentrations. Cracking changes the deformation behaviour of the crash box, and the ability to absorb energy by deformation is reduced when extensive cracking occurs.

One method of improving the ductility in a bearing member for a vehicle is disclosed in US5492207. Here the bearing member is subjected to a heat treatment to change the mechanical properties of the material from which the

bearing member is constructed. As a result the deformation behaviour of the material is improved.

There is therefore a desire to provide an improved method of modifying the deformation behaviour in such structural members, the goal being to achieve a fast and low cost method that is versatile in its applicability to different types of structural member.

In accordance with the invention we provide a method of determining a heat treatment to apply to a structural member, so as to modify the deformation behaviour of the structural member when subjected to an applied stress, the method comprising:-

simulating the deformation behaviour of the structural member when subjected to the applied stress; and,

simulating the effect of at least one heat treatment upon the at least part of the structural member so as to determine a heat treatment to apply to the at least part of the structural member, to produce the modified deformation behaviour.

The use of heat treatments to control the deformation behaviour avoids many of the high costs and stress concentration problems associated with prior methods. We have also realised that great benefit is provided by the simulation of deformations and of heat treatments applied to the structural member. In each case the need for expensive physical test pieces is avoided and the number of simulations that may be performed is therefore unlimited.

Simulations of the deformation behaviour allows detailed analysis of the behaviour of the structural member when under stress such that particular regions of, for example stress concentrations, high strain or cracking, can be located. The properties of the structural member can then be set within the simulation to analyse the effect of such modifications upon the deformation behaviour.

Likewise, the simulation of heat treatments provides information upon how the properties of the structural member will be affected as a result of the heat treatment.

This allows a suitable heat treatment to be selected in order to provide particular properties at particular locations within the structural member.

The simulation of the deformation behaviour and/or the heat treatments can be performed using an analytical model of a particular structural member. However, typically the simulation of the deformation and/or simulation of the heat treatment are performed using a numerical modelling method. Such methods are particularly suitable in the case of complex geometries and the numerical modelling is therefore typically performed using a finite element method. Finite elements provide a very versatile tool in simulating either of the deformation behaviour or the heat treatment for the structural member.

In the case of the heat treatment, this may be simulated as a general heat treatment applied to all parts of the structural member simultaneously although preferably the heat treatment simulation is performed with a localised heat source. The heat source may also be movable within the simulation.

Typically the heat treatment is modelled by considering the flow of heat through the structural member and preferably a heat treatment is determined such that the simulated temperature generated in the structural member is less than the melting temperature for the material. This is because, in general, the structural integrity of the member must be maintained.

The heat treatment simulation may also comprise a microstructural simulation, so that the change in the microstructure of the material of the structural member is simulated as a result of the heat treatment. Microstructural changes have a corresponding effect upon the material properties of the structural member although the degree to which such changes affect the material properties is dependent on the material used.

The heat treatment in the simulation is preferably defined by one or more parameters and typically a number of

heat treatments are simulated by varying one such parameter. Typical parameters include, the travel speed of the source, the heat input, the heat intensity distribution, or the maximum temperature of the source.

Preferably the determination of the heat treatment to apply to the structural member is performed automatically. This may be achieved by inverse modelling or other iterative procedures. Such automatic selection may involve a large number of simulations and therefore high performance computer systems are preferred for this task. The automatic selection may also involve the selection of a heat treatment from a number of simulated heat treatments, each of these being generated as a result of varying the heat treatment parameter.

In principle the structural member may be any component in which a particular function is required in accordance with the geometry and material properties of the member. The structural member may therefore be a strength member in a structure or an impact protection member for a vehicle. Typically the structural member is metallic and formed from a suitable alloy chosen for the specific application. Typical alloys include those containing aluminium such as age hardening aluminium alloys, or ferrous alloys such as steels.

The heat treatment or deformation simulations may be applied to all or part of the structural member in question. However, typically the method further comprises selecting one or more regions forming part of the structural member in accordance with the simulated deformation. The one or more regions are therefore preferably selected as a result of a deformation simulation where particular properties exhibited by the structural member during deformation have been identified.

Each region may therefore be selected in accordance with a deformation property such as ductility, stress, strain, elongation or a fracture property. The choice of property for selecting the region(s) is dependent upon not

only the application but also material used for the structural member. Generally such regions are identified where a particular threshold in the selected property is passed. Such a threshold may be a material property such as the yield stress or alternatively it may be a target threshold assigned by a user. In the case of an assigned threshold, the method preferably further comprises repeatedly:

simulating the deformation of the structural member having the assigned deformation property threshold in each region;

comparing the simulated deformation with a desired behaviour; and,

assigning a new target threshold and/or new region(s); until the desired deformation behaviour is simulated.

A region may therefore be assigned a particular threshold in a property and the effect of the deformation using that particular property can then be determined and compared with a desired deformation behaviour. A user of the simulation can therefore repeatedly modify the deformation behaviour at will by selecting appropriate thresholds and also appropriate regions.

The heat treatment is then preferably determined so as to produce a deformation behaviour meeting the target threshold in each region.

Preferably, the selection of the one or more regions in which to apply a corresponding heat treatment is therefore also performed automatically, for example as part of the simulation. The automatic selection of the regions can be based upon those regions in which the strain in the material has exceeded a user defined threshold.

Although a desired deformation behaviour may be simulated and subsequently a heat treatment determined so as to cause this deformation behaviour, preferably the method further comprises simulating the deformation behaviour of the structural member in the heat treated condition. This enables the user to check that the desired

deformation behaviour will be produced. In some cases, this will be the case although in others there is the possibility of a change in the overall deformation behaviour of the structural member for example by stress transfer. Further regions may then be identified in which a suitable heat treatment should be performed.

Having performed the simulations described, the method preferably further comprises applying the determined heat treatment(s) to a physical structural member workpiece as represented by the simulation. It is desirable to use a similar heat source to that simulated and therefore the determined heat treatment(s) are preferably applied using a localized controllable heat source. This may take the form of a laser such as a diode laser or induction coil.

The method may also be extended to in-line analysis modification wherein structural member workpieces are analysed on a production line so as to generate monitored data. This may involve in-line dimensional analysis and material testing such as hardness testing in order to determine the strength of the material for each workpiece. A simulation of the deformation behaviour may therefore be performed using the monitored data and a suitable heat treatment determined so as to provide a tailored heat treatment for the particular workpiece.

However, in many cases as the material properties and dimensions will not greatly vary, it is possible to produce simulations and corresponding heat treatments for a range of potential properties and dimensions of structural members such that the monitored data may be compared with that used in the simulations and a corresponding heat treatment simply selected for example using a look-up table.

There are a number of applications in which the method according to the invention may be applied. However, the method is particularly advantageous for use in the automated industry in the modification of the deformation behaviour of a vehicle impact member as mentioned earlier.

Such members include bumper beams and crash boxes along with side impact bars and other components designed to protect passengers from an impact.

According to the present invention it is therefore possible to make use of higher strength alloys by modifying the ductility in specific areas of the product which are subjected to high strains. Moreover, as a supplement or replacement of physical geometrical features, the user can actively introduce local changes in the strength and ductility distribution in the workpiece. Special heat treatment patterns can also be used to increase the energy absorption of a structural member when subjected to large dynamic loads.

Such design features are not only invisible, but they are also highly cost-effective in implementation compared to the alternative processes of making complex protrusions, embossments, stampings and so on. The latter may represent impossible or at best very unpractical fabrication steps for certain structures.

Some examples of the method according to the present invention will now be described with reference to the accompanying drawings, in which:-

Fig. 1 shows a flow chart of the method according to a first example;

Fig. 2 shows a bumper beam model of known type;

Fig. 3 shows a deformation in a bumper beam during a crash;

Fig. 4a shows the heat treatment of a bumper beam;

Fig. 4b shows the temperature gradient in the work piece during a heat treatment;

Fig. 4c shows the yield stress gradient in the work piece after a heat treatment;

Fig. 5 shows a crash box model according to a second example;

Fig. 6 shows a crash box with protrusions of known type;

Fig. 7a shows a graph of applied force for deformation versus time in the crash box;

Fig. 7b shows a graph of the applied force for deformation versus time in the heat treated crash box;

Fig. 8a shows the crash box used as an example to obtain the deformation curves of Figures 7a and 7b;

5   Fig. 8b shows the crash box of Figure 8a after an impact has caused deformation;

Fig. 9a shows the temperature gradient during heat treatment of the a crash box;

Fig. 9b shows the yield strength gradient after heat

10   treatment of the crash box;

Fig. 10a shows a T-joint according to a third example;

Fig. 10b shows the T-joint with forces applied to it;

Fig. 10c shows a graph of energy absorbed by the T-joint;

Fig. 11a shows the T-joint after heat treatment;

15   Fig. 11b shows the T-joint after heat treatment with forces applied to it; and,

Fig. 11c shows a graph of energy absorbed by the heat treated T-joint.

The flowchart in Figure 1 shows the steps in

20   determining the location and extent of a heat treatment to apply to a structural member. The flow chart is here further explained referring to an example describing a bumper beam testing procedure. However, it will be obvious to a person skilled in the art that the flow chart and

25   simulation method is generally applicable to procedures where it is desired to modify the deformation behaviour in a structural member exposed to stress.

Figure 2 shows a bumper beam model 1 of known type constructed from an aluminium alloy. In a normal crash

30   situation, a force F will be applied on the bumper beam 1 as indicated by the arrows. Due to the applied force, the bumper beam deforms as indicated in Figure 3. The impact forces leave dents 2 on the bumper beam as can be seen in Figure 3, in which cracks are likely to occur. If cracks

35   form in a structure, the ability to absorb energy is largely reduced. The main functionality of a bumper beam is to absorb energy and it is therefore important to avoid the

forming and propagation of cracks. There are some important considerations when modifying the properties of a bumper beam 1. If the bumper beam 1 is too easy to deform, it will not absorb enough impact energy to avoid
5   structural damage. On the other hand, if the bumper beam 1 is too hard to deform, the stress load required to start the deformation will be too high. The bumper beam 1 will then transfer the stresses through the crash box into the vehicle body, thereby causing damage along with injury to
10 the passengers.

In order to solve the cracking problem, a simulation of the deformation behaviour is performed upon a model of the bumper beam 1, with given values for yield strength, wall thickness and so on, and the applied force F. This is
15 shown in step 100 of Figure 1. The modelling is performed using a finite elements method implemented by software running upon a computer workstation.

At step 101 of Figure 1, the results of the simulated deformation are analysed. This may involve determining
20 whether the deformation behaviour meets standards required by a motoring manufacturer or regulatory authority.

In the present example the required standards are not met and therefore at step 102 of Figure 1, the strain of the material during the deformation is used to define one
25 or more regions within the structural member where the strain due to the applied force F is the greatest. These regions are the most at risk from cracking during a crash situation. The region(s) where dents or cracks are likely to occur are therefore defined and the finite element
30 method is used to bound these regions.

When the geometrical positions of the regions where crack propagation is likely to occur have been predicted and mapped, the next step is to carry out numerical modelling to determine a suitable heat treatment. A heat
35 treatment is selected and modelled individually for each selected region at step 103. The simulated heat treatment in this case is applied using a localised heat source

(analogous to laser heating) and this heat source is also allowed to move so as to traverse each region. Typical parameters defining the heat treatment include the travel speed, direction and the intensity distribution.

5   Again, a finite element model is used to monitor the heat flow within the material of the bumper beam 1. The evolution of the microstructure of the bumper beam in the heated region is also simulated as this directly influences the material properties.

10   The heat treatment parameters may be selected automatically based upon previously provided data, or alternatively, the user of the simulation model may enter the values directly.

When using high intensity heat sources it is important
15 to avoid any melting of the heated regions particularly for alloys having low melting points such as aluminium. One of the important issues is therefore to calculate heat intensities and trajectories that do not cause any melting of the surface. It is also important to control the extent
20 of the heat affected zones in order to avoid too large changes in the overall mechanical properties of the structure. Distortions of the product may also occur as a consequence of thermally induced deformations although these can be predicted within the model.

25   The maximum temperature and the extent of micro structural changes in the heated zones are thus found. As a result the new material properties of each region are determined. In this case, the important property to control for a given strain is the ductility of the
30 material. Typically bumper beams are designed to have high strength properties in the region 3 (see Figure 3) suffering the direct impact. However, the regions 4,5 usually do not require high strength and it is more important to prevent crack propagation (and therefore to
35 absorb energy) in these regions 4,5.

An example of a suitable heat treatment upon an identified region 6 is shown in Figure 4a. The region 6 is

identified as one in which extensive deformation is normally experienced. In order to avoid cracking in this region a heat treatment is determined to soften the material in the region 6, the simulated heat treatment being performed using a localised and moveable heat source 8 such as provided by a laser beam. The direction of travel of the heat source is shown at 7 in Figure 4a.

The region 6 is situated on the top wall 4 of the bumper beam and a corresponding region is situated on the lower wall 5 (see Figure 3). In Figure 4a the heat source 8 has passed along the region 6 leaving a soft zone.

In this example a Gaussian distribution function is used to simulate the heat source. The heat source has a net heat input of 1800 W and a travel speed of 50 mm/s. 95% of the heating effect is produced within a distance of 10 mm from the centre of the source.

A heated zone in the bumper beam wall follows the heat source 8 during the simulated heat treatment. The zone has a temperature gradient as indicated in Figure 4b, the maximum temperature attained being about 350°C. Around the heat source the temperatures are high, descending rapidly as the beam moves along its path. The result in the bumper beam wall 4 is a region with a noticeably lowered yield strength and increased ductility, forming a soft line along the region 6 on the bumper beam 1.

Figure 4c shows the simulated difference in yield strength. The region 6 has a predicted yield strength of around 140 MPa while the surrounding structure has a yield strength of 260 MPa. This reduction in yield strength is accompanied by approximately a 100% increase in elongation to fracture for the alloy of the beam in this example, AA6082.

Returning to Figure 1, the predicted properties of the material within the region 6 are then compared with the desired properties at step 104. The desired properties are either those chosen automatically or by the model user.

If the changes in ductility due to the heat treatment of the specified zones are insufficient, a new heat treatment is determined at step 105 for the bumper beam in the state prior to heat treatment. Typically this involves using modified input values for the heat source intensity and travel speed. Steps 103, 104 and 105 may be repeated a number of times and the loop is terminated when melting of the material is avoided and the change in ductility has reached a desired value.

If however, after the first or one or more subsequent heat treatments, the ductility is found to be acceptable then the simulation process ends at step 106 as a suitable deformation and heat treatment have been identified.

However, in order to check that the heat treatment determined has the desired effect, typically the simulation of the deformation behaviour is then performed again at step 107, using the modified material properties for the bumper beam 1. Due to the increased ductility of the material within the region 6, the deformation behaviour is improved.

Should the material response to the applied stress still show an unwanted behaviour, further regions are mapped upon the heat treated bumper beam 1, before a new coupled thermal-microstructural simulation is carried out with modified input data (steps 102, 103...). Otherwise, at step 108 the simulations are stopped.

When a suitable heat treatment has been determined for each region, these can then be applied to a real life bumper beam. Of course an analogous heat source should be used according to the heat treatment parameters of the simulation so as to increase the accuracy of the method.

A modification can be made to the above method in that the steps 100 to 102 can be performed repeatedly using different material property values for the regions selected prior to determining the heat treatment. For example, a user of the model may wish to identify regions within each simulated deformation and assess the effect of changing the

material properties for those regions. This may in turn produce further regions of extensive strain.

In providing the user with the ability to determine the position of the regions and/or the properties within those regions, a preferred deformation behaviour can be arrived at prior to the performance of any heat treatment simulations. This accelerates the overall speed of the method as processor time is not wasted in determining heat treatments for unsuitable deformations. The subsequent heat treatment for each region is then determined in order to produce the desired properties in the selected regions. This alternative is shown as "Alt.2" in Figure 1.

A second example of the method is now described in the determination of a heat treatment to modify the deformation behaviour of a crash box.

A typical crash box 10 is shown in Figure 5, constructed from an aluminium alloy. An end plate 11 is welded, bolted or other-wise attached to the bumper beam. The front 12 of the crash box 10 is attached to the main structure of the vehicle. When a force F is applied on the bumper beam, the crash box 10 will deform and absorb part of the energy of the impact.

In order to control the deformation behaviour of the crash box 10, it is known to arrange protrusions or recesses 13 in the side walls, as shown in Figure 6. This has the disadvantage of requiring more complicated processing of the component and accordingly it incurs greater expense in manufacture.

Figure 7a shows a graph from a crash test upon a crash box, indicating the applied force (Y axis) necessary to attain deformation in a typical crash box of known type as a function of time (X axis). The first peak 14 in Figure 7a shows the force necessary for any deformation to occur in the crash box. The next peak 15 indicates a hardening face in the deformation pattern. The second peak 15 shows that parts of the crash box start deforming only at a higher level of force. However, in crash box design it is

known that improved safety performance results from delaying the maximum forces to later times in the impact. To improve this deformation behaviour the zones causing the second peak 15 are firstly detected and then softened.

5   In this case the regions were selected by a user, based upon experience. However, equally an analysis using the method described above could have been performed for the crash box 10, the position and extent of regions of high strain being calculated as a result of the deformation
10   simulation.

Corresponding values were then assigned to the identified regions and an appropriate heat treatment determined for each, under the constraint that no melting of the material occurred as a result of each heat
15   treatment. The resultant heat treatments were then applied to a real crash box 10' of the same specification as that simulated, in order to soften the regions and improve the deformation behaviour.

Figure 7b shows a graph equivalent to that of Figure
20   7a for the crash box 10'. In Figure 7b the deformation of the crash box with soft zones starts at the same critical force level as the crash box without soft zones. After the deformation has started in the crash box 10', the forces applied to the crash box can be seen to be more constant
25   through the deformation course. The second peak 15 which occurred in the previous example is eliminated due to the heat treatment. As indicated by the first peak in Figure 7b, soft zones are introduced through heat treatment without losing the overall energy absorbing capacity of the
30   crash box.

Figure 8a shows the simulated undeformed crash box 10 having the response shown in Figure 7a. Figure 8b shows the simulated deformation behaviour of the crash box 10' corresponding to Figure 7b.

35   Fig. 9a shows the extent of the local heat treatment upon the crash box 10'. This results in soft zones of lower yield stress being generated within the crash box 10'

as indicated in Figure 9b. The material will also experience some strength recovery upon prolonged natural ageing or upon an artificial ageing heat treatment, although this is not shown in the figure.

5   A third example of the method is now described with reference to a welded T-joint. Figure 10a shows a typical welded T-joint commonly seen in many structures. In the weld metal 20 in the joint, the material is generally more brittle as is well known. Due to the location of the weld

10   20 partly in a corner where the highest stresses will occur, cracking in the joint often becomes a problem as illustrated in Figure 10b. The energy absorbed by the T-joint before deformation is dependent on the force applied to the beam 21 and on the displacement of the beam

15   21. If the displacement is small, the energy E_1 absorbed is correspondingly small as seen on the graph of Figure 10c. This is an important factor for example in vehicle structures which are constructed to tolerate as high forces of impact as possible during collision without damaging the

20   passengers.

        A way to solve the lack of ductility in the construction, is to perform the method described in connection with Figure 1. Regions of high stress and strain in the T-joint are mapped through a simulation of the

25   structure when it is subjected to external forces. Cracking may occur because of too low ductility in the joint and surrounding areas. A solution to the ductility problem is to introduce a soft zone in a region 22 in the beam 21 above the weld.

30   It should be noted that this region 22 does not correspond to that in which the cracking or fracture is most likely to occur as the weld metal does not respond as well to heat treatments as the base material. To achieve the soft zone in the region 22, a suitable heat treatment

35   scheme is predicted through simulation. The beam 21 is then heat treated in accordance with the determined heat treatment so as to generate a local soft zone 22 as shown

in Figure 11a. This soft zone distributes plastic deformation over a larger area and the structure thereby absorbs more deformation energy.

This concept is schematically illustrated for the
5　T-joint 20 containing a soft zone 22 which acts to divert high strains away from the brittle weld 20 and thus avoid early fracture of the structure. The beam 21 will bend in the soft zone 22, avoiding cracking of the weld 20 as shown in Figure 11B. A graph of the energy E_2 absorbed is
10　schematically shown in Figure 11c for comparison with a corresponding graph for the untreated structure in Figure 10c. With the increased displacement of the beam 21, the energy absorbed during deformation is increased.

The above methods can also advantageously be used for
15　in-line material modification in a production process. Fabrication of crash components or systems comprising for example a set of crash boxes and a bumper beam are subject to strict tolerances with respect to chemical composition of the alloys and geometrical dimensions. These factors are
20　paramount in order to meet the carefully designed behaviour of the system during a crash.

However, process tolerances inherent in fabricating parts from materials such as extruded aluminium will sometimes result in final parts that exhibit deviations
25　from the designed energy absorbing capacity. Particularly problematical is the occurrence of alloys with higher yield stresses than anticipated or parts that have higher gauge thicknesses. Under such circumstances the part may not collapse properly and plastic deformation may translate
30　further into the vehicle structure.

A solution to this problem is to use the method described above as part of an inline modification method with continuous simulation and adjustment of the mechanical properties of the components during production.
35　At the start of the production, the properties of the alloy in the workpiece are determined by automatic hardness measurement or alternatively by some real-time chemical

analysis. In addition the gauge thickness of the most critical areas are measured. This can be done optically, mechanically, with eddy currents or any other practical means. The resulting material response according to the
5   parameters is simulated, thereby mapping any critical regions. If the response shows unwanted energy absorbing behaviour, a corrective step is performed by subjecting one or several areas of the part to a short thermal cycle that appropriately renders the mechanical properties in selected
10   regions from a maximum strength condition to a softened material.

As the variations in the strength and dimensions of such components is likely to be within certain boundaries, it is feasible to simulate suitable heat treatments for a
15   range of possible strength and dimensional variations. An appropriate heat treatment can then be selected from these predetermined simulated heat treatments which avoids the need for repetitively performing similar simulations. This has a corresponding speed advantage.

20   The heating is preferably conducted by induction coil, plasma, gas flame, laser or other confined heat sources but without any melting of the material. It has previously been shown by simulation that such rapid temperature cycles may significantly change the nature of collapse and total
25   energy absorption of a crash box.

As an addition to heating as a softening operation, it is also feasible to remove a calculated amount of material by rapid machining of one or several selected areas. In addition, exposure to strong chemical etching in a
30   predetermined period can remove the desired material.

Preferably and advantageously, the heat treatment scheme is developed for a flexible high-intensity heat source. With the use of a controlled direct diode laser or possibly specially designed induction coils, it is possible
35   to facilitate fine lines, spots or intricate patterns that posses material properties substantially different from the adjacent base material.

The method according to the present invention is not limited to heat treatments in which heat is applied as illustrated by the above examples. In some cases, based on the performed simulation, a suitable cooling treatment may

5   be applied as part of the fabrication process, as an appropriate way of modifying the material properties of the structural members. A heat treatment using controlled coding can be applied as part of a hot fabrication process.

One of the challenges resolved by the present method

10   is to find the sufficient amount of heating preventing the material from melting. It is a great advantage of the method according to the invention that these values are found through simulation before any full scale testing.

It is also an important issue of the method that it is

15   possible to define and control the extent of the heating, thereby determining the exact extent of the heat affected zone. Due to the highly concentrated heating, it is possible to limit the heat treatment much more exactly than according to formerly known heat treatment methods.

CLAIMS

1.   A method of determining a heat treatment to apply to a structural member, so as to modify the deformation
5   behaviour of the structural member when subjected to an applied stress, the method comprising:-
     simulating the deformation behaviour of the structural member when subjected to the applied stress;
     simulating the effect of at least one heat treatment
10   upon the at least part of the structural member so as to determine a heat treatment to apply to the at least part of the structural member, to produce the modified deformation behaviour.

2.   A method according to claim 1, wherein the simulation
15   of the deformation is performed using a numerical modelling method.

3.   A method according to claim 1 or claim 2, wherein the simulation of the heat treatment is performed using a numerical modelling method.

20   4.   A method according to claim 2 or claim 3, wherein the numerical modelling comprises a finite elements method.

5.   A method according to any of the preceding claims, wherein the heat treatment is simulated with a localised heat source.

25   6.   A method according to any of the preceding claims, wherein the heat treatment is simulated with a moveable heat source.

7.   A method according to any of the preceding claims, wherein the heat treatment is determined such that the
30   simulated temperature generated in the structural member is less than the melting temperature for the material.

8.   A method according to any of the preceding claims, wherein each heat treatment is defined by a parameter and wherein a number of heat treatments are simulated by
35   varying the parameter.

9.   A method according to claim 8, wherein the heat treatment parameter describes one of the travel speed of

the heat source, the heat input, the heat intensity distribution or the maximum temperature of the heat source.

10. A method according to any of the preceding claims, wherein the heat treatment is determined automatically.

11. A method according to any of the preceding claims, wherein the method further comprises selecting one or more regions forming part of the structural member in accordance with the simulated deformation.

12. A method according to claim 11, wherein each region is selected in accordance with a deformation property.

13. A method according to claim 12, wherein the deformation property is selected from a ductility, stress, strain, elongation or fracture property.

14. A method according to claim 12 or claim 13 wherein each region is selected at a location in the structural member in accordance with a threshold in the deformation property.

15. A method according to any of claims 12 to 14, further comprising assigning a target threshold to the deformation property for each region.

16. A method according to claim 15, further comprising repeatedly:-

simulating the deformation of the structural member having the assigned deformation property threshold in each region;

comparing the simulated deformation with a desired behaviour; and,

assigning a new target threshold and/or new region(s);

until the desired deformation behaviour is simulated.

17. A method according to claim 15 or claim 16, wherein the heat treatment is determined so as to produce a deformation behaviour meeting the target threshold in each region.

18. A method according to claim 17 when dependent upon claim 16, wherein the deformation behaviour produced is the desired deformation behaviour.

19. A method according to any of claims 11 to 18, wherein the selection of each region is performed automatically.

20. A method according to any of the preceding claims, further comprising simulating the deformation behaviour of the structural member in the heat treated condition.

21. A method according to claim 20 when dependent upon

5   claim 11, further comprising repeating the method to identify further regions for subsequent heat treatment.

22. A method according to any of the preceding claims, further comprising applying the determined heat treatment(s) to a structural member workpiece.

10   23. A method according to claim 22, wherein the determined heat treatment(s) are applied using a localised controllable heat source.

24. A method according to claim 23, wherein the heat treatment(s) are applied using a laser or induction coils.

15   25. A method according to any of claims 22 to 24, further comprising monitoring a received structural member workpiece so as to generate monitored data, wherein the simulation of the deformation behaviour is performed using the monitored data.

20   26. A method according to claim 25, wherein the heat treatment for each region is selected from a group of predetermined heat treatments for the structural member.

27. A method according to any of the preceding claims, wherein the structural member includes at least two

25   substructural members welded together.

28. A method according to any of the preceding claims, wherein the structural member is a vehicle impact member.

29. A computer program comprising computer program code means adapted to perform the method according to any of

30   the preceding claims.

30. A computer program according to claim 29, embodied on a computer readable medium.

Start

100

101

Material response
to deformation OK
?

YES

Alt. 2

NO

102

103

Modify:
• Heat intensity
• Heat distribution
• Travel speed

105

107

104

YES

Melting OK ?
Ductility OK ?

NO

108

106

Stop

FIG. 1

FIG. 2

FIG. 3

FIG. 4A

T(°C)

350

300

250

200

150

FIG. 4B

σ_y(MPa)

260

240

220

200

180

160

140
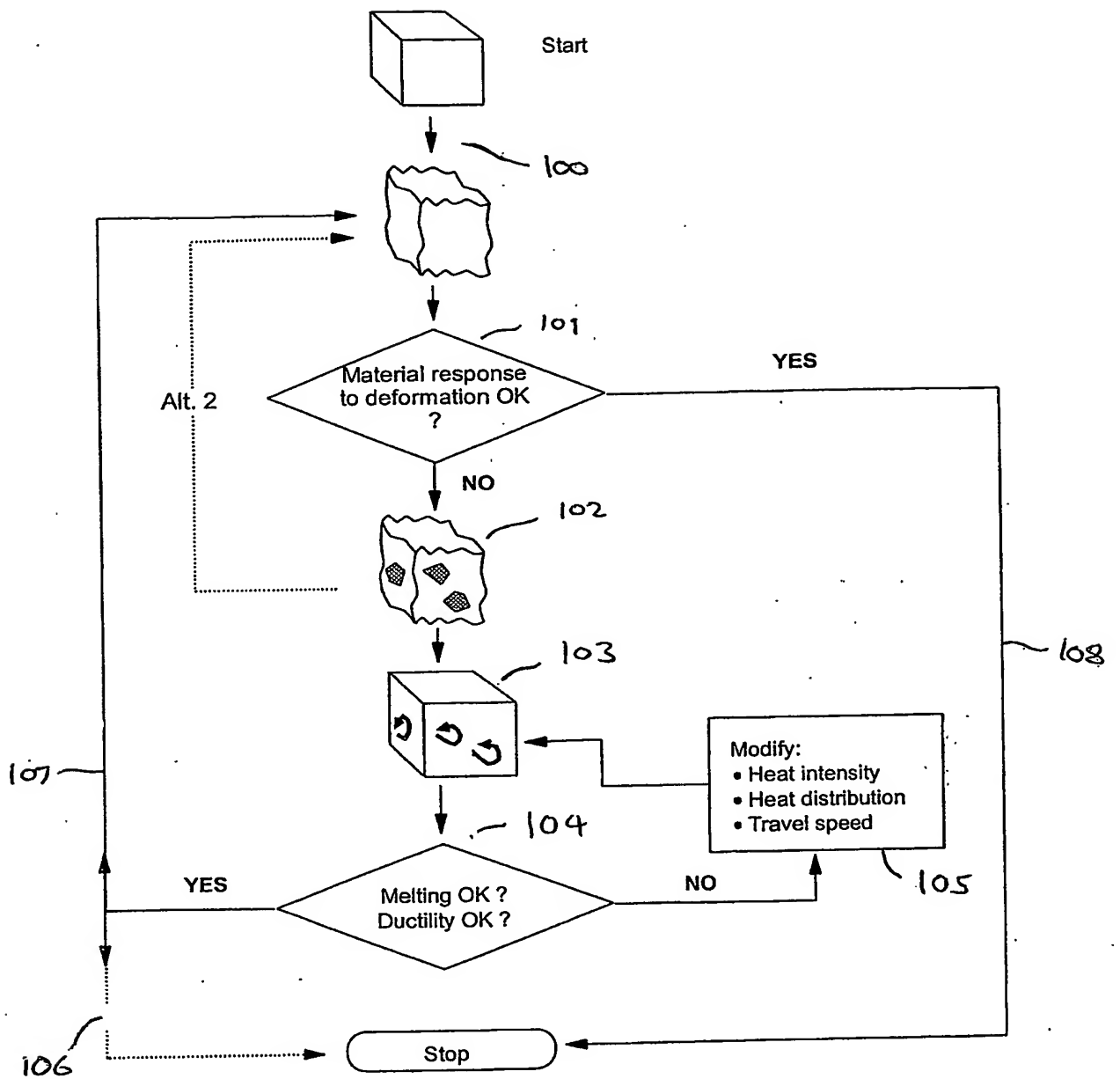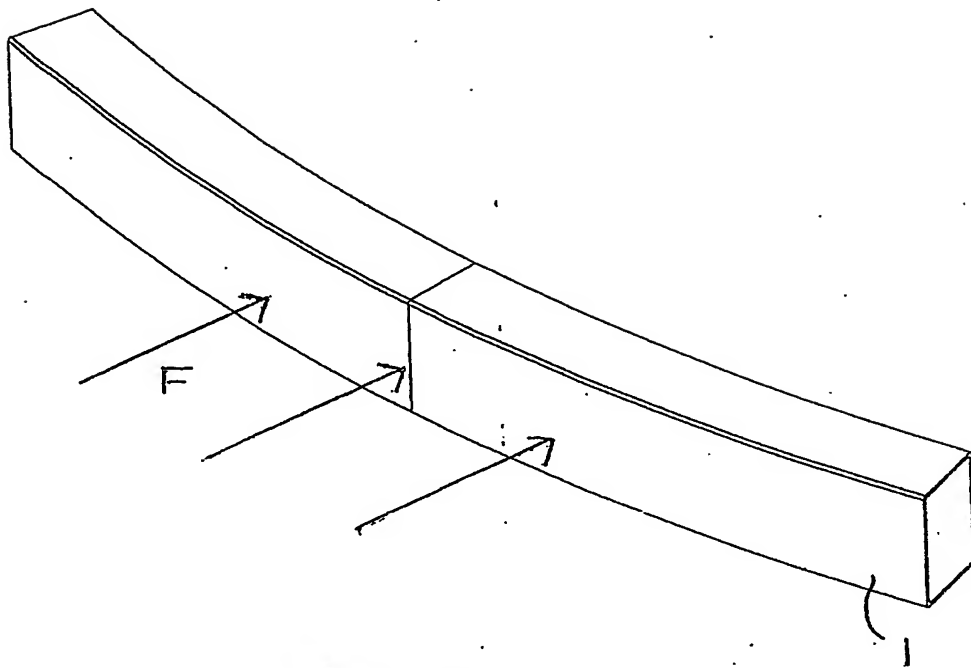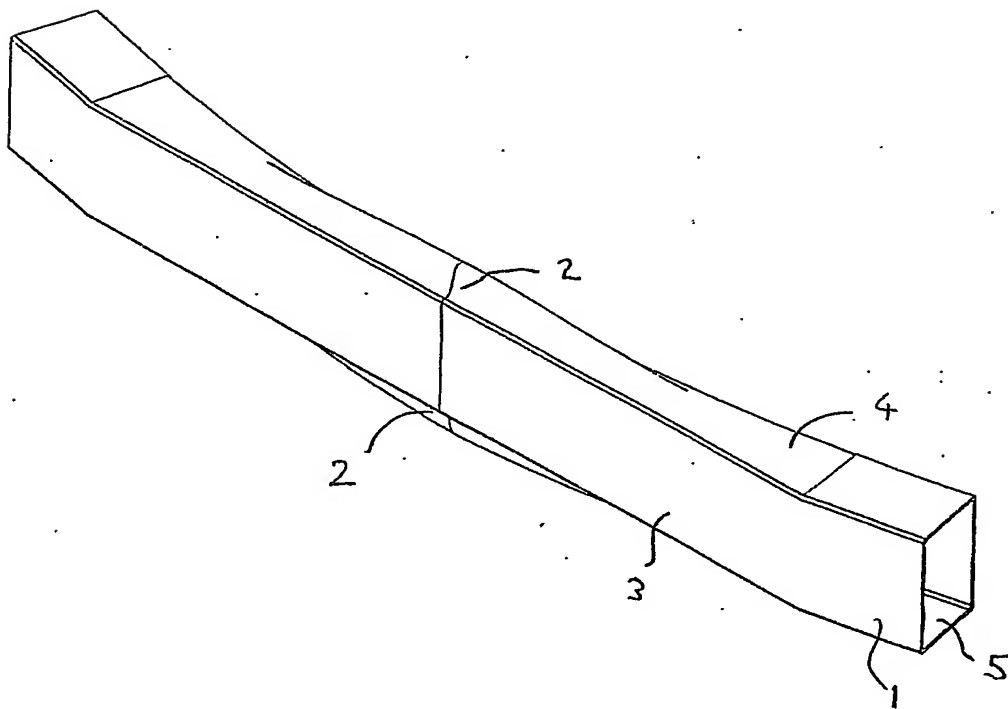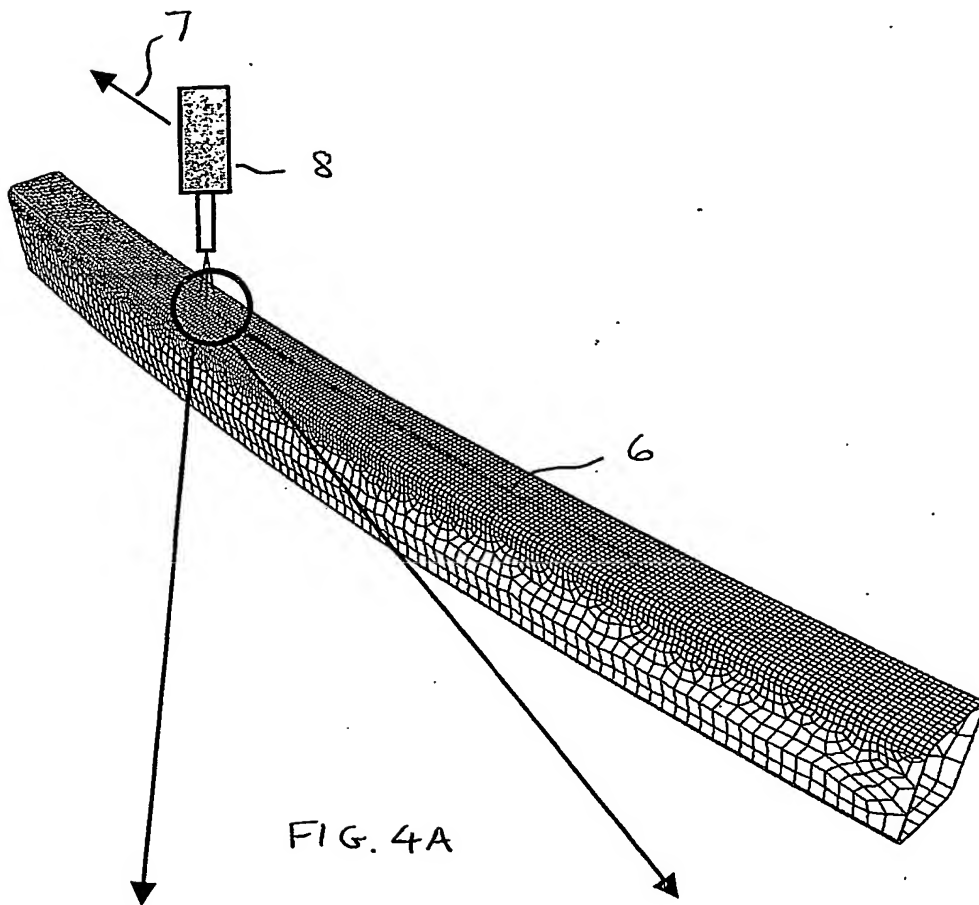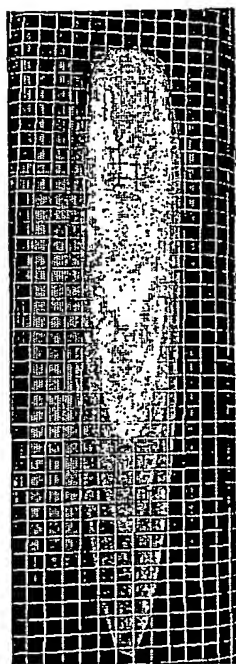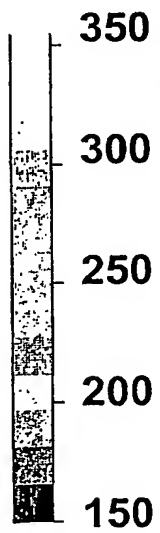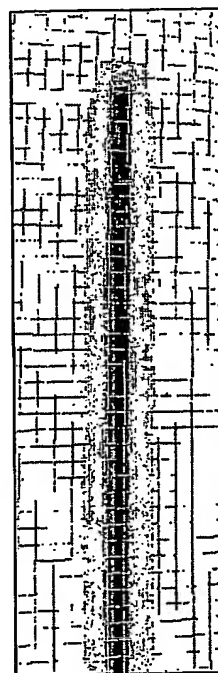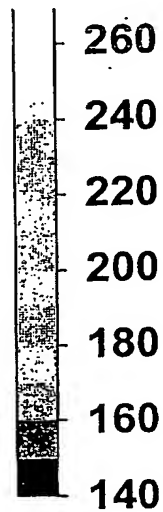
FIG. 4C
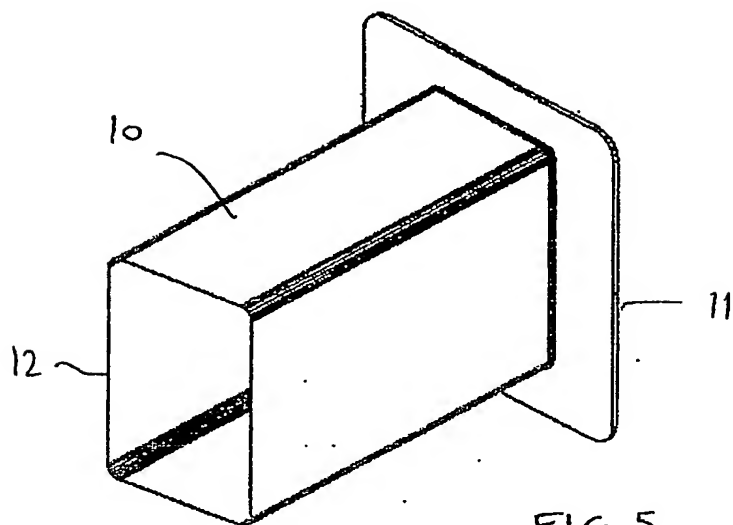
FIG. 5
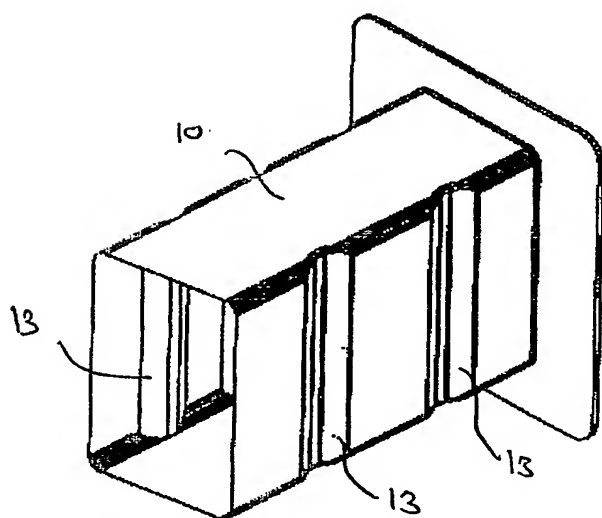
Fig. 6
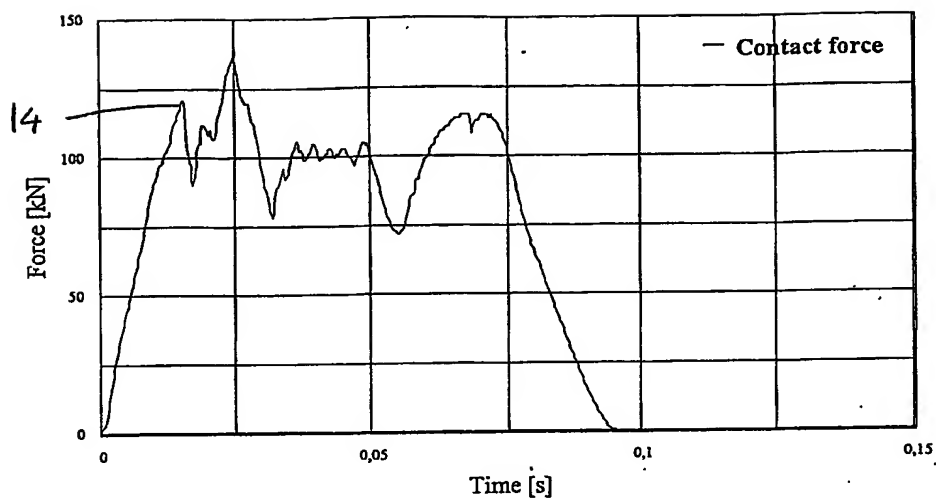
FIG. 7A

FIG. 7B

FIG. 8A

FIG. 8B

260
200
150
100
50
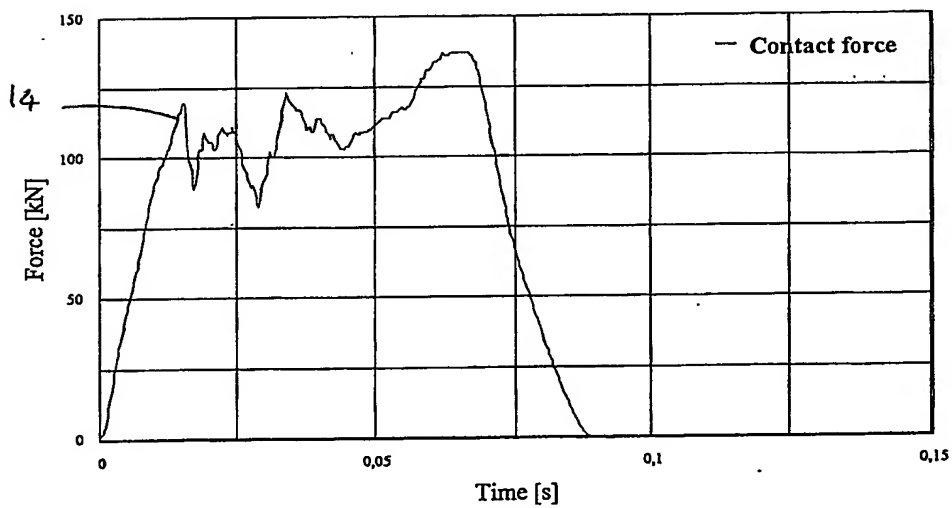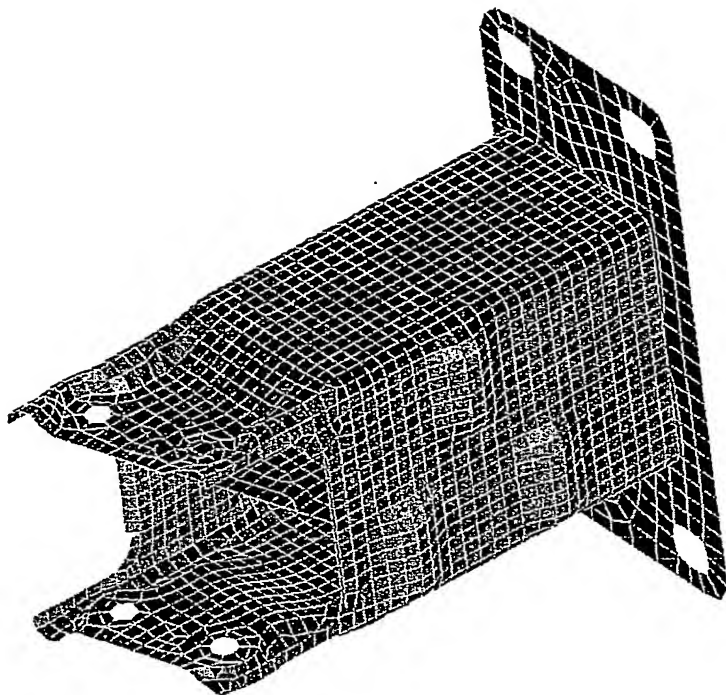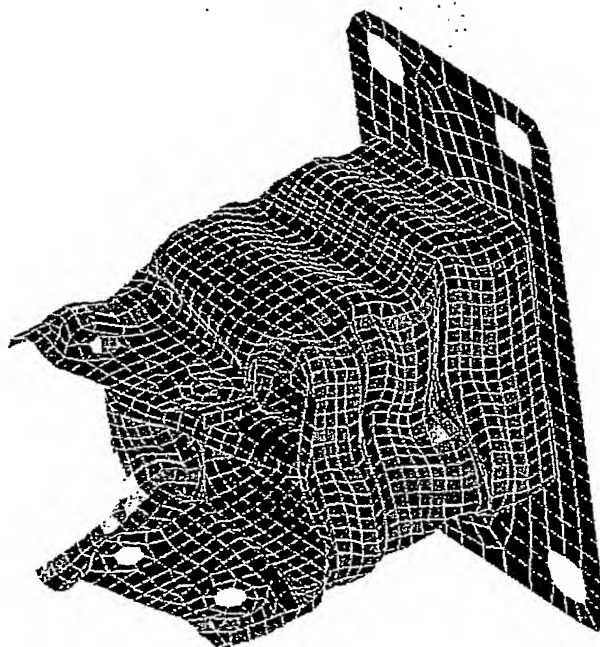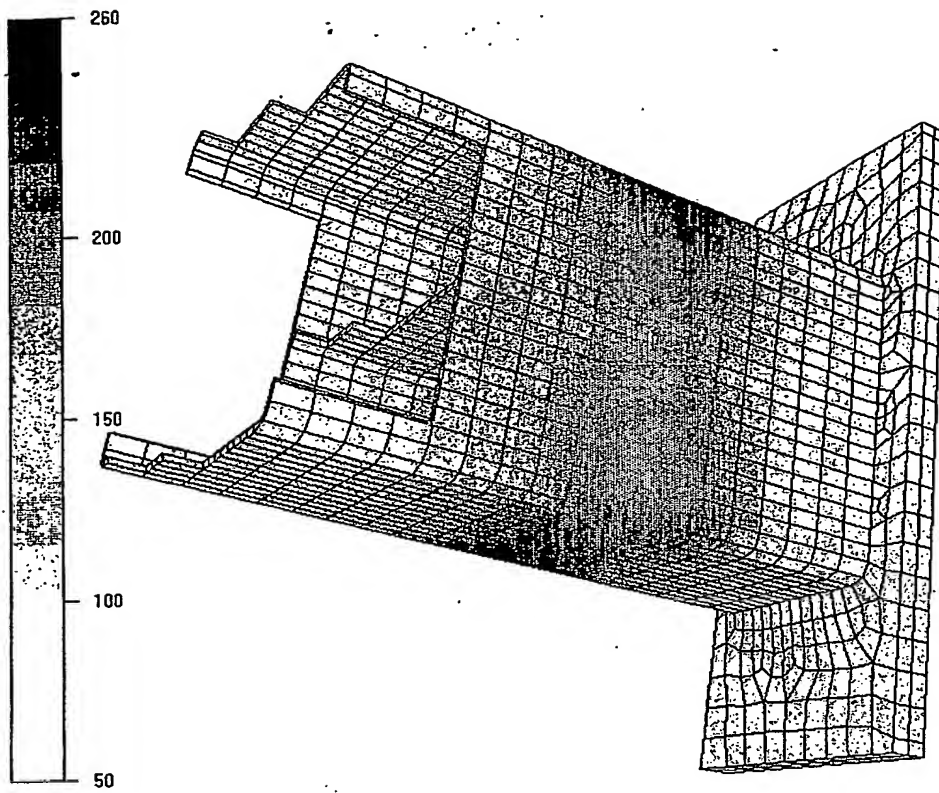
Temperature field [C°]   FIG.9A

280
260
240
220
200
180
160
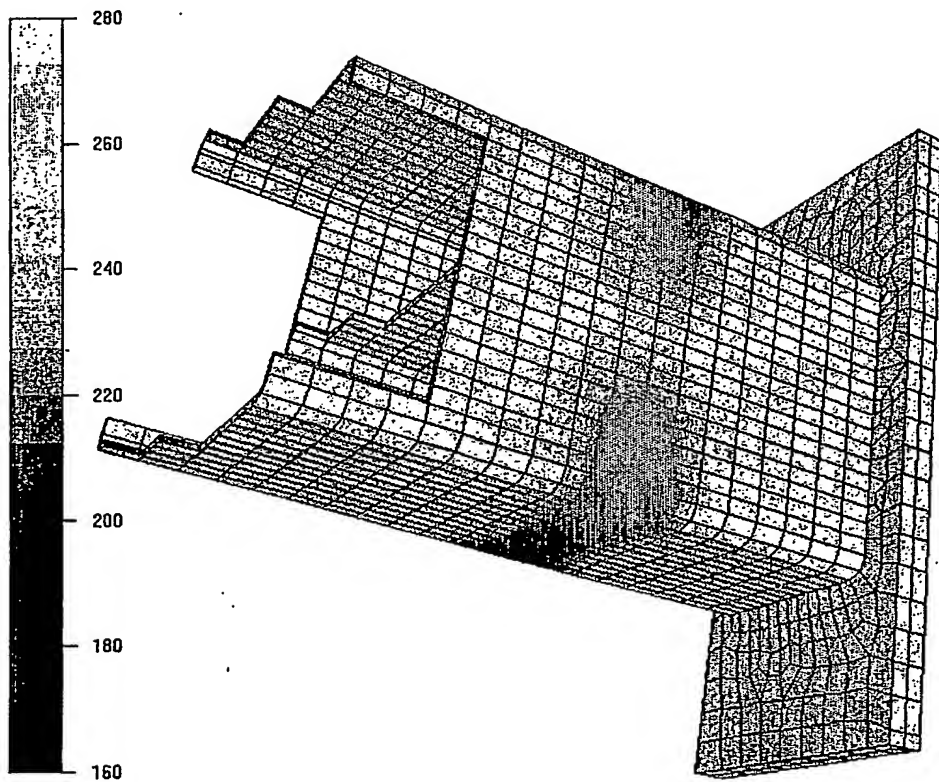
Yield stress [MPa]   FIG.9B

FIG. 10A

20   21

FIG. 10B

F

FIG. 10C

Force

E_1

Displacement

FIG. 11A

22   21

FIG. 11B

F

FIG. 11C

Force

E_2

Displacement